10/PRTS

09/868251
JC18 Rec'd PCT/PTO 15 JUN 2001

PCT/EP99/09966
Clean Specification
Attorney Docket No. 127FR/49857

Controlled Acoustic Waveguide for Sound Absorption

Background of the Invention

[0001] This application claims the priority of PCT International No. PCT/EP99/09966 filed December 15, 1999 and German Priority Document 198 61 018.1 filed December 15, 1998, the disclosures of which are expressly incorporated by reference herein.

[0002] The present invention relates to a controlled acoustic waveguide for sound absorption in the manner of an elongate hollow chamber which communicates with a sound--transmitting duct via an opening on its first end surface. The longitudinal resonances may be tuned to a sound spectrum to be attenuated, by detecting the membrane vibrations with a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of the hollow chamber and by inverting the microphone signal with an amplifier and by feedback of the inverted microphone signal to the loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

[0003] Sound absorbers are known for attenuating low-frequency noise in ducts, wherein the longitudinal resonances of elongate hollow chambers, so-called acoustic waveguides, are utilized, e.g. in accordance with the DE 19612572 or Lamancusa, J.S.: "An actively tuned passive muffler system for engine silencing". Proceedings Noise-Con 87, 1987, pp. 313 - 318. These waveguides are coupled to the sound-transmitting duct via

an opening in the end surface thereof and either project orthogonally from the duct or conform thereto while extending in parallel therewith. For the first longitudinal resonance in particular, at which the length of the chamber corresponds to one quarter of the wavelength of the first resonance frequency, high attenuation levels are achieved over a narrow band. This limitation of the frequency range is, however, problematic when either a wide-band absorption is required or when the noise spectrum changes which was taken as a basis when the waveguide was dimensioned, The necessary adaptation of the chamber length is implemented, at least in stages, according to Lamancusa, by the provision of very long chambers with compartments from the very beginning, which may provision of very long chambers with compartments from the very beginning that be opened or closed whenever this is necessary. Another possibility of avoiding the inexpedient narrow-band restriction consists in the simultaneous application of different chamber lengths according to the German Document 196 12 572.

[0004] Another group of sound attenuators or absorbers for low frequencies comprises resonant cavities, i.e. both acoustic waveguides according to Okamoto, Y.; Boden, H.; Abom, M.: "Active noise control in ducts via side-branch resonators" in: Journ. of the Acoust. Soc. of America 96 (1994), No. 9, pp. 1533 - 1538, and equally Helmholtz resonators according to DE 4226885 or the US Patent No. 5233137, which are connected to a sound-transmitting duct or space via an opening and which have properties suitable for variation by electro-acoustical or active components, respectively. These systems share the joint approach that at least one microphone is present in the duct or space. The sound pressure signal so detected is initially filtered, amplified and subjected to further analysis

steps and then serves as control variable for at least one loudspeaker in the waveguide or cavity. As a result, the loudspeaker emits a signal which, again upon modification by the resonator, is superimposed with opposite phase onto the sound at the site of the microphone in the duct or cavity, so effecting attenuation of the sound. With these actively influenced resonators, it is possible, on the one hand, to generate and hence also attenuate high sound pressures at low frequencies while, on the other hand, at least the loudspeaker is protected from potential, e.g. thermal, loads in the duct. The disadvantages of these methods include the fixed dimensioning of the resonators independently of possible variations of the sound spectrum in the duct, which is initially taken as a basis, and the lack of protection of the microphone.

[0005] According to DE 4027511, a passive sub-system is used instead of the resonant cavities so far mentioned, which consists preferably of passive absorber layers and protecting cover layers. In this case, too, the function of the electro-acoustical components mounted on the rear side relates to the modification of the passive absorber, aiming at the generation of a theoretically optimum acoustic impedance on the front side of the absorber, which impedance promise the highest propagation attenuation possible in the connected sound-transmitting duct. This method requires that a signal-shaping circuit proposed in DE 4027511 firstly compensates the intrinsic characteristics of all the electro-acoustic components (microphone, loudspeaker, box, etc.) and secondly imprints on the system the desired terminating impedance. The characteristics of the components have been thoroughly studied and described. In accordance with the results the conversion

of this method into practice inevitably requires the implementation of complex transmission functions of the signal-shaping circuit, which cannot be realised in practical application except in approximation.

[0006] Reactive sound absorbers are operative without any additional passive layers or resonance systems according to WO 97/43754, wherein the membrane of a loudspeaker is a direct component of the wall in a sound-transmitting duct and wherein the membrane vibrations controlled or amplified with a feed-back circuit take a direct influence on the sound field in the duct. The adaptation to a sound spectrum to be attenuated, which is also necessary in this case, is based on the dimensioning of the resonance system consisting of the membrane mass and the pneumatic cushion in the form of the rear volume, which exists there-behind.

SUMMARY OF THE INVENTION

[0007] It is an object of the present invention to improve the efficiency of sound attenuation in ducts or the like and to reduce the manufacturing costs of the inventive device.

[0008] This problem has been solved by the device of the present invention in which the longitudinal resonances of said hollow chamber are tunable to a sound spectrum to be attenuated, by detecting the membrane vibrations by a microphone located directly in front of the membrane of at least one loudspeaker on the second end surface of said hollow chamber, and by inverting the microphone signal by an amplifier and by feedback of the inverted microphone signal to said loudspeaker in an amplified form in dependence on a signal from a sensor, which is characteristic of the sound in the duct.

[0009] The advantages of the present invention over existing sound absorber includes the following features:

[0010] In distinction from known acoustic waveguides, the controlled waveguide of the present invention achieves a high sound attenuation at low frequencies at a reduced structural volume (with the length of the hollow chambers reduced by up to roughly four times).

[0011] The frequency range with a high sound absorption of the inventive controlled waveguide is extended to roughly two octaves due to the adaptivity to variable acoustic spectrums.

[0012] The controlled waveguide of the present invention is characterized by a simple structure and particularly by a low-price analog amplification and control without expensive electronic filters or digital signal analysis,

[0013] Furthermore, all the electro-acoustic components in the hollow chamber of the controlled waveguide of the present invention are protected from influences produced by flow, dust and aggressive media in the duct over rather long periods.

[0014] This protection is also extended to high temperature, e.g. in exhaust gas systems, because the inventive controlled waveguide offers various possibilities of an efficient thermal decoupling from the duct.

Brief Description of the Drawings

[0015] Other objects, advantages and novel features of the present invention will become apparent from the

following detailed description of the invention when considered in conjunction with the accompanying drawings.

[0016] Fig. 1 is a schematic view of the controlled waveguide in accordance with the present invention;

[0017] Fig. 2 is a schematic view of an embodiment of the controlled waveguide with a thermal insulating layer between the hollow chamber and the duct, with cooling elements as part of the wall of the hollow chamber, with a forced cooling thermal exchanger, as well as with an absorbing inner wall cladding ;

[0018] Fig. 3 is a schematic view of another embodiment of the controlled waveguide of the present invention with a subdivision of the hollow chamber into several tubes of different lengths;

[0019] Fig. 4 is a schematic view of still another embodiment of the controlled waveguide with a conventional passive attenuator on the opposite duct wall (with dimensions indicated in mm);

Sub B1 **[0020]** Fig. 5 is a graph of insertion attenuation measured on the controlled waveguide according to Fig. 4, with and without amplification;

SUB B2

[0021] Fig. 6 ~~is a graph of insertion attenuation measured on the controlled waveguide according to Fig. 4, with amplification at an air temperature of 20 °C and 150 °C in the duct;~~

[0022] Fig. 7 is a schematic view of a controlled waveguide with a hollow chamber projecting obliquely from the duct;

[0023] Fig. 8 is a schematic view of a controlled waveguide with a hollow chamber conforming to a bent duct;

[0024] Fig. 9 is a schematic view of a controlled waveguide with an aerodynamically expedient configuration and positioning in the manner of a central slide inside a large duct; and.

[0025] Fig. 10 is a schematic view of yet another embodiment of a controlled waveguide

DETAILED DESCRIPTION OF THE DRAWINGS

[0026] The starting point of the controlled waveguide according to Fig. 1 consists in an elongate hollow chamber (1) presenting distinct longitudinal resonances. The chamber (1) is acoustically connected via an opening (2) on the first end surface (3) to a sound-transmitting duct (4) or space. The length L of the hollow chamber (1) is dependent on the sound spectrum occurring in the duct (4), wherein the frequencies with the greatest sound amplitude vary within a defined range,

e. g. as a consequence of a varying gas temperature in the duct (4), as a function of the operation. In this case the length L corresponds to roughly one quarter of the wavelength of the upper limit frequency of this range.

[0027] The membrane (8) of at least one loudspeaker (9) is provided on the second end surface (6) of the hollow chamber (1), in front of another cavity (7), with the cavity (7) acting as air cushion and the membrane (8) as planar mass forming a resonance system. A microphone (10) is positioned directly in front of the membrane for detecting the membrane vibrations. The microphone signal is applied on the input of an inverting amplifier (11) with an adjustable gain, which produces an output signal, which serves to control the loudspeaker (9).

[0028] As a function of the level of amplification the membrane vibrations hence the acoustically effective length of the hollow chamber (1) undergo a variation, with the acoustic length being definitely (roughly four times) greater than the actual length L. The acoustically effective prolongation of the hollow chamber (1), which is achieved on account of the increased amplification, means a shift of its first longitudinal resonance towards lower frequencies, expediently up to the lower limit of the frequency range of the sound spectrum occurring in the duct (4). The setting of the gain is based on the control signal of at least one additional sensor (12) which supplies a parameter to the amplifier (11) that is characteristic of the frequencies having the highest sound amplitude in the duct.

[0029] Temperature sensors in the duct (4), rotational speed detectors on ventilators, generators or motors or engines, as

well as elements measuring the gas flow of burners and exhaust systems may be enumerated as examples of a sensor (12). The sensor (12) is expediently operative without particular protective measures such as those required, for instance, in microphones in an exhaust system. An exemplary and particularly simple configuration of the sensor (12) is a temperature-dependent resistor which detects the temperature in the duct (4) and constitutes, at the same time, an element of the feedback branch of an inverting amplifier (11) known per se and hence controls the overall gain achieved by this amplifier. Further expedient embodiments include the application of voltage- and current-controlled amplifiers (11) which broaden the range of contemplated sensors (12) available for selection.

[0030] A sound-transmitting cover (5) consisting of perforated sheet, non-woven material, sheet material or the like is provided in front of or behind the opening (2) leading to the duct (4) for protection from a possible soiling of the hollow chamber (1) and from entering hot exhaust gas from the duct (4). As a function of structural conditions in the environment of the duct (4), the hollow chamber (1) may be configured in a straight or curved shape, project obliquely or orthogonally from the duct, or conform against the duct (4) in the longitudinal direction. In this case, a thermal insulating layer (13) is disposed between the hollow chamber (1) and the duct (4), as may be seen in Fig. 2. Whenever the hollow chamber (1) must be expected to be heated, the cooling elements (11) illustrated in Fig. 2 as part of the wall of the hollow chamber improve the dissipation of heat in the same manner as a forced cooling of the kind of a thermal exchanger (15) or with so-called Peltier elements in the hollow chamber. A transverse subdivision (16) of the hollow chamber (1) into several tubes

of different lengths as well as an absorbing inner wall cladding (17) constitute another advantageous embodiment of the inventive controlled waveguide (Fig. 3) so as to achieve a broader-band attenuation.

[0031] Fig. 4 illustrates an embodiment of the inventive controlled waveguide in which the attenuation levels achieved in combination with a conventional passive attenuator (18) on the opposite duct wall, which are indicated in Fig. 5, represent the two boundary cases in the frequency range as a function of the set gain (11). The contrastive indication of the attenuation measured at 20 °C and 150 °C in the duct, which is presented in Fig. 6, emphasizes the low influence of temperature on the attenuation of the inventive controlled waveguide according to Fig. 4.

[0032] Figs. 7 through 10 show further embodiments of the controlled waveguide of the present invention. Similar reference numerals have been used to designate parts having functions similar to the described in conjunction with the embodiments of Figs. 1 through 4

[0033] The foregoing disclosure has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the disclosed embodiments incorporating the spirit and substance of the invention may occur to persons skilled in the art, the invention should be construed to include everything within the scope of the appended claims and equivalents thereof.